CLAIMS

What is claimed is:

1. A yaw stability system for a vehicle having a plurality of wheels each with a torque control element, said yaw stability system comprising:

a yaw rate sensor measuring a vehicle yaw rate;

a plurality of braking devices each operably associated with one of the torque control elements and configured to exert a braking torque on the control element in response to a control command; and

a control unit communicating with said yaw rate sensor and configured to

identify a desired yaw rate,

determine a yaw rate tracking error based on the difference between the desired yaw rate and the vehicle yaw rate,

determine a yaw condition of the vehicle based on the vehicle yaw rate,

determine a control yaw moment to minimize the yaw rate tracking error,

select one or more of said plurality of braking devices based on the yaw condition, and

communicate a control command to the one or more selected braking devices to induce said control yaw moment.

2. The yaw stability system of claim 1 wherein said control unit determines the control yaw moment using a sliding mode control law based on a lumped mass vehicle model.

3. The yaw stability system of claim 2 wherein said control unit determines the control yaw moment (Mz) based on the following equation

$$M_z = I_{zz}\dot{r}_{des} - [a[(C_{FL} + C_{FR})\alpha_F \cos\delta + (\eta_{FL} + \eta_{FR})F_{zF} \sin\delta] - b(C_{RR} + C_{RL})\alpha_R +$$
$$(c * C_{FL} - d * C_{FR})\alpha_F \sin\delta - c(\eta_{FL}F_{zF} \cos\delta + \eta_{RL}F_{zR}) + d(\eta_{FR}F_{zF} \cos\delta + \eta_{RR}F_{zR})] + I_{zz}\eta SAT(\frac{r_{des} - r}{\phi})$$

4. The yaw stability system of claim 1 wherein said braking devices are electromagnetic retarders and wherein said control command is a current command.

5. The yaw stability system of claim 4 wherein said electromagnetic retarders are eddy current machines.

6. The yaw stability system of claim 5 wherein the control unit estimates braking device saturation torque (T_{est}) based on a quadratic function of rotor speed and excitation current.

7. The yaw stability system of claim 6 wherein the quadratic function is:

$$T_{est} = f_0(\omega) + f_1(\omega) * i + f_2(\omega) * i^2$$

8. The yaw stability system of claim 7 wherein the coefficient functions $f_0(\omega)$, $f_1(\omega)$, and $f_2(\omega)$ are estimated from steady state test data performed for various rotor speeds.

9. The yaw stability system of claim 8 wherein the coefficient functions $f_0(\omega)$, $f_1(\omega)$, and $f_2(\omega)$ are defined by

$$f_i(\omega) = a_{i0} + a_{i1}\omega + a_{i2}\omega^2$$

and wherein the parameters α_{ij} are estimated through a least square fit based on the steady state test data.

10. The yaw stability system of claim 9 wherein the coefficient functions $f_0(\omega)$, $f_1(\omega)$, and $f_2(\omega)$ are estimated by recalculating the coefficient functions $f_0(\omega)$, $f_2(\omega)$, and $f_2(\omega)$ for each rotor speed based on the estimates of parameters α_{ij} and the parameters α_{ij} are then estimated based on the recalculated coefficient functions $f_0(\omega)$, $f_1(\omega)$, and $f_2(\omega)$ through a least square fit based on the steady state test data.

11. The yaw stability system of claim 4 wherein said control unit is an open loop controller providing a current optimal torque without a current feedback signal from the electromagnetic retarder.

12. The yaw stability system of claim 4 wherein the control unit is a parametric model control unit.

13. A method for controlling yaw in a vehicle having front left, front right, rear left, and rear right wheels and a plurality of braking devices each associated with one of the wheels, said method comprising:

determining a vehicle yaw rate;

determining a desired yaw rate;

calculating a yaw rate error based on the difference between the desired yaw rate and the vehicle yaw rate;

determining a control yaw moment using a sliding mode control law based on a lumped mass vehicle model;

selecting one of the braking devices based on a vehicle yaw condition;

determining a control command for the selected braking device based on the control yaw moment; and

communicating the control command to the one or more selected braking devices.

14. The method of claim 13 wherein the step of determining a control command further includes determining a required torque for the selected braking device, said required torque being the torque required from the selected braking device to induce the control yaw moment.

15. The method of claim 14 wherein the plurality of braking devices are eddy current machines, wherein the control command is a current command, and wherein the step of determining the current command further includes determining a saturation torque for the selected braking device based on a quadratic function of control element speed and excitation current.

16. The method of claim 15 wherein the step of determining the current command further includes comparing the saturation torque for the selected braking device to the required torque.

17. The method of claim 16 wherein the step of determining the current command further includes determining a command current for the selected braking device if the required torque is less than the saturation torque.

18. The method of claim 16 wherein, if the required torque is greater than the saturation torque, the step of communicating the current command further includes sending a saturation current command to the selected braking device, selecting a second braking device, and sending a second current command to the second braking device to cause the second braking device to exert a torque equal to the difference between the control yaw moment and the saturation torque, and wherein the first and second selected braking devices are on the same lateral side of the vehicle.

19. The method of claim 15 wherein the step of determining the saturation torque (T_{est}) is based on the following equation:

$$T_{est} = f_0(\omega) + f_1(\omega) * i + f_2(\omega) * i^2$$

and wherein the method further includes estimating the coefficient functions $f_0(\omega)$, $f_1(\omega)$, and $f_2(\omega)$ from steady state test data performed for various rotor speeds.

20. The method of claim 19 wherein the coefficient functions $f_0(\omega)$, $f_1(\omega)$, and $f_2(\omega)$ are defined by

$$f_i(\omega) = a_{i0} + a_{i1}\omega + a_{i2}\omega^2$$

and wherein the step of estimating the coefficient functions $f_0(\omega)$, $f_1(\omega)$, and $f_2(\omega)$ includes estimating parameters α_{ij} through a least square fit based on the steady state test data, includes recalculating the coefficient functions $f_0(\omega)$, $f_2(\omega)$, and $f_2(\omega)$ for each rotor speed and based on the estimates of parameters α_{ij}, and re-estimating the parameters α_{ij} based on the recalculated coefficient functions $f_0(\omega)$, $f_1(\omega)$, and $f_2(\omega)$ through a least square fit based on the steady state test data.

21. The method of claim 13 wherein the step of determining the control yaw moment includes calculating the control yaw moment based on a derivative of the desired yaw rate.

22. The method of claim 13 wherein the step of determining the control yaw moment includes calculating the control yaw moment based on a saturation function.

23. The method of claim 13 wherein the step of determining the control yaw moment includes calculating the control yaw moment (M_z) based on the following equation:

$$M_z = I_{zz}\dot{r}_{des} - [a[(C_{FL} + C_{FR})\alpha_F \cos\delta + (\eta_{FL} + \eta_{FR})F_{zF} \sin\delta] - b(C_{RR} + C_{RL})\alpha_R +$$
$$(c * C_{FL} - d * C_{FR})\alpha_F \sin\delta - c(\eta_{FL}F_{zF} \cos\delta + \eta_{RL}F_{zR}) + d(\eta_{FR}F_{zF} \cos\delta + \eta_{RR}F_{zR})] + I_{zz}\eta SAT(\frac{r_{des} - r}{\phi})$$

24. A method of estimating the retarding torque of an electromagnetic retarder having a control element, said method comprising:

modeling the estimated retarding torque of the retarder (T_{est}) based on the following quadratic function of a velocity (ω) of the control element and a magnitude of a retarder excitation current (i)

$$T_{est} = f_0(\omega) + f_1(\omega) * i + f_2(\omega) * i^2$$

estimating coefficient functions $f_0(\omega)$, $f_1(\omega)$, and $f_2(\omega)$ from steady state test data performed for various rotor speeds.

25. The method of claim 24 wherein the coefficient functions $f_0(\omega)$, $f_1(\omega)$, and $f_2(\omega)$ are defined by

$$f_i(\omega) = a_{i0} + a_{i1}\omega + a_{i2}\omega^2$$

and wherein the step of estimating the coefficient functions $f_0(\omega)$, $f_1(\omega)$, and $f_2(\omega)$ includes estimating parameters α_{ij} through a least square fit based on the steady state test data.

26. The method of claim 25 wherein the step of estimating the coefficient functions $f_0(\omega)$, $f_1(\omega)$, and $f_2(\omega)$ includes recalculating the coefficient functions $f_0(\omega)$, $f_2(\omega)$, and $f_2(\omega)$ for each rotor speed and based on the estimates of parameters α_{ij}.

27. The method of claim 26 wherein the step of estimating the coefficient functions $f_0(\omega)$, $f_1(\omega)$, and $f_2(\omega)$ further includes re-estimating the parameters α_{ij} based on the recalculated coefficient functions $f_0(\omega)$, $f_1(\omega)$, and $f_2(\omega)$ through a least square fit based on the steady state test data.

28. An electromagnetic retarder assembly comprising:

an electromagnetic retarder having a stator with conductive windings and a rotor rotatable relative to said stator;

a sensor sensing a rotational speed of the rotor and generating signals indicative of the rotational speed;

a controller communicating with said sensor to receive said signals, said controller configured to communicate an excitation current to said electromagnetic retarder and to estimate the retarding torque of the retarder (T_{est}) based on a quadratic function of the velocity of the rotor and the magnitude of the excitation current.

29. The electromagnetic retarder assembly of claim 28 wherein the quadratic function is:

$$T_{est} = f_0(\omega) + f_1(\omega) * i + f_2(\omega) * i^2$$

30. The electromagnetic retarder assembly of claim 29 wherein the coefficient functions $f_0(\omega)$, $f_1(\omega)$, and $f_2(\omega)$ are estimated from steady state test data performed for various rotor speeds.

31. The electromagnetic retarder assembly of claim 30 wherein the coefficient functions $f_0(\omega)$, $f_1(\omega)$, and $f_2(\omega)$ are defined by

$$f_i(\omega) = a_{i0} + a_{i1}\omega + a_{i2}\omega^2$$

and wherein the parameters α_{ij} are estimated through a least square fit based on the steady state test data.

32. The electromagnetic retarder assembly of claim 31 wherein the coefficient functions $f_0(\omega)$, $f_1(\omega)$, and $f_2(\omega)$ are estimated by recalculating the coefficient functions $f_0(\omega)$, $f_2(\omega)$, and $f_2(\omega)$ for each rotor speed based on the estimates of parameters α_{ij}.

33. The electromagnetic retarder assembly of claim 32 wherein the parameters α_{ij} are estimated based on the recalculated coefficient functions $f_0(\omega)$, $f_1(\omega)$, and $f_2(\omega)$ through a least square fit based on the steady state test data.

34. The electromagnetic retarder assembly of claim 29 wherein the controller is an open loop controller providing a current optimal torque without the need for a current feedback signal from the retarder.

35. The electromagnetic retarder assembly of claim 34 wherein the controller is a parametric model control unit.